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Period-K magnitude relations of variable stars in the LMC

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Abstract. We cross-correlated the OGLE-II database with the SIRIUS JHK survey data in the Large Magellanic Cloud (LMC). After eliminating obvious spurious variables, we determined the pulsation periods for 9 681 stars by applying the Phase Dispersion Minimization (PDM) technique to the OGLE-II data. Based on these data, we studied the period-K magnitude (PK) relations of variable stars in the LMC and found a new sequence. Comparison between the theoretical pulsation model (Wood & Sebo 1996) and observational data suggests that the variable stars on the new sequence are Mira variables pulsating in the first overtone mode.

1. Introduction

We are now conducting a near-infrared (NIR) JHK monitoring survey toward the Magellanic Clouds using the Infrared Survey Facility (IRSF) at the South African Astronomical Observatory at Sutherland. The IRSF consists of a 1.4-m alt-azimuth telescope to which is attached an NIR camera, SIRIUS. We have been monitoring a total area of 3 deg^2 along the LMC bar since 2000 December, and a total area of 1 deg^2 around the SMC center since 2001 July. In this paper we deal with the single-epoch data from the monitoring survey. Details of the survey and data reduction are found in Ita et al. (2002, 2003).

2. Cross-identification and period determination

The SIRIUS data and all the stars found by the OGLE-II survey in the LMC were cross-identified using a simple positional correlation. We found 35 783 matches within a search radius of 3″ (29 228 out of 35 783 stars are within an 1″ radius). We applied the PDM technique (Stellingwerf 1978) to the OGLE-II data to determine the light variation periods of the cross-identified stars. We assigned one pulsation period to each variable star, and the multi-periodic stars (e.g., Bedding et al. 1998) were not analyzed. Finally, periods were determined for 9 681 variables.

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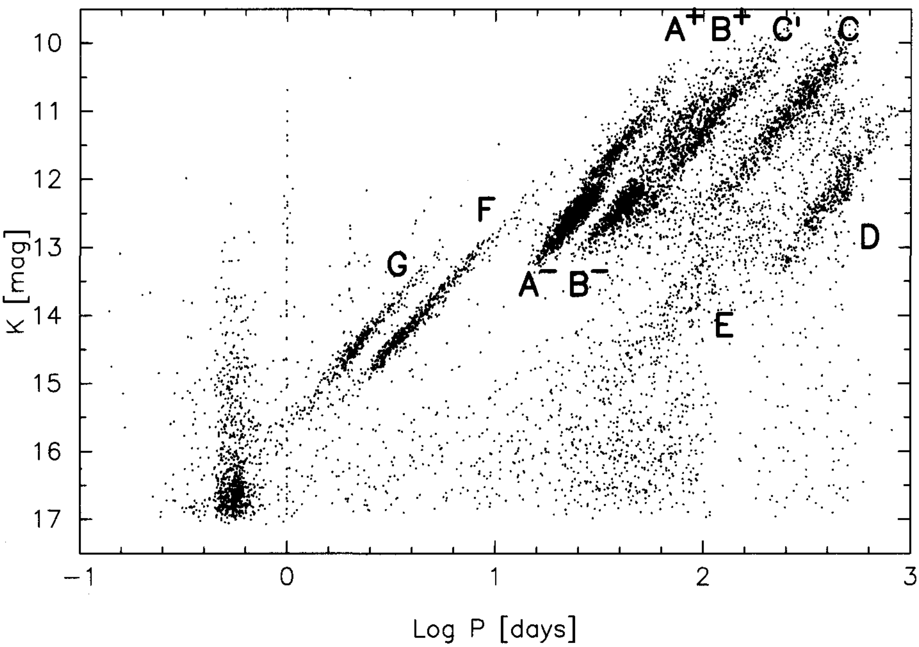

Figure 1. Period-K magnitude diagram for OGLE variables in the LMC.

3. Results and Discussion

3.1. Period-K magnitude diagram

Wood (2000) found that radially pulsating red giants in the LMC form parallel sequences in the PK plane. Cioni et al. (2001) and Lebzelter, Schultheis & Melchior (2002) confirmed Wood's result. In Fig. 1 we show the relationship between the determined pulsation periods and the K magnitudes of the cross-identified variables. The labels of the sequences are named in analogy to the ones found by Wood (except C', F and G). This is essentially the same diagram as the ones obtained by previous studies. However, the sample used here is much larger, and we can see new features: (1) the sequences A and B of Wood (2000) seem to be composed of the upper and lower sequences (A^+, B^+) and (A^-, B^-); (2) the sequence B of Wood (2000) separates into three independent sequences $B^\pm$ and C' (newly discovered).

Ita et al. (2002) concluded that a significant fraction of variable stars below the TRGB ($K \sim 12.1$) could be on the RGB. Since the sequences A^+ and B^+ exceed the luminosity of the TRGB, they consist of intermediate-age population and/or metal-rich old population AGB stars. However, the interpretation of the sequences A^- and B^- is difficult. If the metal-poor and old AGB stars pulsate in the same mode as the more massive stars on the sequences A^+ or B^+, they should be located on the sequences A^- or B^- because they do not exceed the TRGB.

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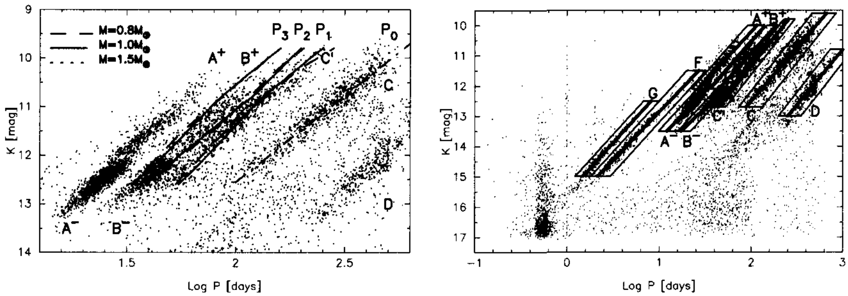

Figure 2. (a – left) The same as Fig. 1, but compared with the theoretical model of Wood & Sebo (1996). Their models for stars of masses of 0.8, 1.0 and 1.5 $M_\odot$ pulsating in the fundamental mode (P_0, they forced theoretical fundamental mode period to fit the observed Mira relation of Feast et al. (1989)– dot-dashed line) and first (P_1), second (P_2) and third (P_3) overtone modes are shown. (b - right) The same as Fig. 1, but with the classification boxes. The thick solid lines are the least-square fits of a linear relation to stars within each box.

The question is whether the sequences A^- and B^- contain RGB pulsators or not. If AGB stars alone make up the A^- and B^- as well as A^+ and B^+ sequences, the small gap and the horizontal shift between them needs to be explained. If A^- and B^- stars, at least some of them, are pulsating on the RGB, then the discontinuity between the − and + sequences is understood in terms of different evolutionary stages. Though we prefer the RGB interpretation, it should be noted that a definitive answer has not been obtained. Stars on sequences F and G are very regularly pulsating and have periods ranging from less than 1 d to more than 30 d, suggesting that they are Cepheid variables pulsating in fundamental and first overtone modes, respectively. The explanation of sequence D is not clear yet. Stars on the loose sequence E are thought to be contact and semi-detached binaries (Wood et al. 1999).

3.2. Pulsation modes

Wood et al. (1999) suggested that Mira variables (sequence C) are fundamental mode pulsators, while so-called semi-regular variables (sequence A and B) can be pulsating in the first, second or even more higher overtone mode, by comparison of observations with theoretical models. However, a controversy still exists over the pulsation modes of variable red giants. Fig. 2a shows the comparison between the observed PK sequences of pulsating red giants in the LMC and the theoretical models calculated by Wood & Sebo (1996). The location of sequence C is consistent with the LMC Mira sequence observed by Feast et al. (1989). Most of the stars on sequence C' are regularly pulsating just like those on C, but their amplitudes are smaller than those of the C stars. We note, however, that the amplitudes of stars on sequence C' are larger than those of stars on B. The observed periods, luminosities and period ratio of sequences C and C' agree very well with those of the theoretical fundamental (P_0) and first overtone mode (P_1) pulsation models. Also, the theory predicts that overtone pulsators have smaller amplitudes than fundamental ones. Therefore, all of the above observational facts and the agreements with the theory could be naturally explained if we consider that the stars on the sequences C and C' are Mira variables pulsating in the fundamental and first overtone mode, respectively.

3.3. Period-K magnitude relations

In order to determine the PK relations, we defined boundary lines (Fig. 2b) that divide variable stars into nine prominent groups (sequence E is excluded). The thick solid lines are the least square fits of a linear relation to each group, and Table 1 summarizes the calculated PK relations.

Table 1. PK relations for variable stars in the LMC of the form $K = a \times \log P + b$. The K magnitudes are referred to the LCO system. The σ is the standard deviation in K, and N is the number of stars being used in the least squares fitting after applying 3σ clipping.

Group	a	b	σ	N
A^-	-3.284±0.047	17.060±0.065	0.114	1142
A^+	-3.289±0.047	16.793±0.077	0.125	510
B^-	-2.931±0.057	17.125±0.091	0.100	584
B^+	-3.356±0.052	17.634±0.099	0.160	502
C'	-3.768±0.023	18.885±0.046	0.110	693
C	-3.520±0.034	19.543±0.082	0.198	975
D	-3.635±0.078	21.718±0.207	0.198	472
F	-3.188±0.019	16.051±0.013	0.095	540
G	-3.372±0.041	15.574±0.016	0.091	317

References

Bedding, T.R., Zijlstra, A.A., Jones, A., Foster, G. 1998, MNRAS, 301, 1073

Cioni M.-R.L., et al., 2001, A&A, 377, 945

Feast, M.W., Glass, I.S., Whitelock, P.A., Catchpole, R.M. 1989, 241, 375

Ita Y., et al., 2002, MNRAS, 279, L32

Ita Y., et al., 2003, MNRAS, Submitted

Lebzelter, T., Schultheis, M., Melchior, A.L. 2002, A&A, 393, 573

Stellingwerf, R.F. 1978, ApJ, 224, 953

Wood, P.R., Sebo, K.M. 1996, MNRAS, 282, 958

Wood, P.R., et al. 1999, IAU Symp. 191: Asymptotic Giant Branch Stars, 191, 151

Wood, P.R. 2000, PASA, 17, 18

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Discussion

Alves: Between sequences A+ and A1 and B+ and B1 what is period shift (i.e. assuming the same slope)?

Ita: That is not yet measured.

Wood: The shifts of A- and B- are consistent with lower mass (lower temperature).

Kurtz: What are the sequence D and E stars?

Wood: Sequence E stars are binaries (see Wood et al 1999 or Wood 2000). Sequence D stars are discussed by Wood, Olivier and Kawaler in these proceedings.

Feast: Can the period shift between RGB and AGB stars on sequences A and B be explained theoretically?

Ita: The RGB stars have longer periods at a given luminosity than the AGB stars (sequences A and B). This is what would be expected if the RGB stars are of lower mass than the AGB stars (lower M gives lower $T_{\rm eff}$ and larger R on the RGB).

Takeuti: You pointed out the existence of sequence C1. Do you have any characteristics about the amplitudes on it?

Ita: Typical I amplitudes of stars on sequence C1 are $0.5 - 1.0$ mag; stars on sequence C are $0.5 - 3.5$ mag, and stars on sequence B+ are $0.1 - 0.5$ mag, respectively.

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